

CHARACTERIZATION AND APPLICATION  
OF TORREFIED MALAYSIA BIOMASS AS A  
BIOFUEL FOR GASIFICATION

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## **SUPERVISOR'S DECLARATION**

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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CHARACTERIZATION AND APPLICATION OF TORREFIED MALAYSIA  
BIOMASS AS A BIOFUEL FOR GASIFICATION

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## DEDICATION

*In the name of Allah, Most Gracious, Most Merciful*

*To my beloved parents*

*ABDUL WAHID BIN MD ALI & JUNIATI BINTI MOHD NOOR*

*To my lovely wife*

*NURSYAHIDA BINTI EMBONG*

*To my supportive siblings*

*FILZATUS SYAMILA, FILZATUS SYAHIDA & FILZATUS SABIHA*

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## ABSTRAK

Lambakan sisa kelapa sawit dari industri minyak kelapa sawit dan sisa hutan dari aktiviti pembalakan mengakibatkan masalah sisa buangan. Walau bagaimanapun, ia boleh digunakan sebagai sumber tenaga baru dan boleh ditingkatkan bagi menangani kelemahan biojisim dengan menggunakan proses torefaksi. Torefaksi adalah proses pemanasan pada suhu rendah antara 200 °C – 330 °C dalam keadaan lengai. Biojisim yang telah dirawat dengan torefaksi menunjukkan peningkatan ciri-ciri biojisim tersebut dan sesuai untuk proses pengelasan. Setiap kumpulan biojisim mempunyai ciri-ciri tersendiri, maka kajian terhadapnya adalah penting. Sebagai sumber tenaga, nilai haba tinggi adalah penting dan untuk menentukan nilai ini memakan masa yang lama dan terdedah kepada ralat. Masalah ini boleh diselesaikan dengan memperkenalkan korelasi nilai haba tinggi. Objektif kajian ini adalah untuk mengkaji kesan proses torefaksi terhadap suhu dan masa yang berlainan kepada beberapa jenis biojisim, membangunkan korelasi untuk meramal nilai haba tinggi berdasarkan ciri-ciri kimia biojisim dan untuk menunjukkan penggunaan pengelasan biojisim menggunakan biojisim dalam keadaan mentah dan *torrefied*. Sumber biojisim adalah dari sisa kelapa sawit (pelepah sawit, tandan buah kosong, gentian mesokarpa sawit dan tempurung kelapa sawit) serta sisa hutan (habuk kayu meranti, seraya, kulim dan chengal). Biojisim telah dibakar dalam tiub reaktor pada empat suhu yang berbeza (240, 270, 300 dan 330 °C) dengan kehadiran nitrogen pada tiga masa yang berlainan (15, 30 dan 60 minit). Pencirian biojisim mentah dan *torrefied* seperti nilai haba tinggi, jisim dan hasil tenaga, analisis hampiran dan analisis muktamad telah dijalankan. Data analisis digunakan dalam mengangkar korelasi nilai haba tinggi dan simulasi pengelasan lapisan terbendalir. Berdasarkan hasil jisim dan tenaga, masa yang sesuai untuk *torrefied* kedua-dua jenis biojisim adalah pada 30 minit. Untuk analisis muktamad, komposisi karbon untuk kedua-dua sisa kelapa sawit dan sisa hutan memperlihatkan kenaikan manakala komposisi hidrogen dan oksigen menunjukkan penurunan. Dalam analisis hampiran, karbon tetap meningkat sehingga 56 wt% untuk sisa kelapa sawit dan 47 wt% untuk sisa hutan. Nisbah hidrogen ke karbon dan oksigen ke karbon menunjukkan penurunan nilai. Akhir sekali, untuk nilai haba tinggi, nilainya meningkat kerana faktor peningkatan HHV dapat mencapai 1.58 dan 1.41 untuk sisa minyak sisa dan sisa hutan. Bagi model yang meramalkan nilai haba tinggi, korelasi linear berdasarkan analisis hampiran menghasilkan anggaran terbaik manakala untuk sisa kelapa sawit (ralat purata mutlak (AAE): 5.37%) dan sisa hutan (AAE: 10.37%). Dengan menggunakan data yang diperoleh dalam simulasi pengelasan, dicatatkan bahawa biojisim terbaik untuk sisa kelapa sawit adalah pelepah sawit (OPF) manakala untuk sisa hutan adalah habuk kayu kulim. Analisis lanjut menunjukkan bahawa kedua-dua biojisim menghasilkan hidrogen tertinggi apabila suhu pada 700 °C, mempunyai nilai 0.2 untuk nisbah udara kepada biojisim (ABR) dan 1.0 untuk nisbah wap kepada biojisim (SBR). Menggunakan keadaan operasi tersebut, kecekapan gas sejuk (CGE) dan nilai haba rendah (LHV) untuk gas sintesis dapat dikira. Perubahan CGE untuk pelepah sawit berada dalam lingkungan 0.85% hingga 6.29%, manakala untuk Kulim, kenaikan adalah dari 3.0% hingga 8.6%. Untuk LHV gas sintesis, kedua-dua biojisim mempunyai LHV hampir sama kecuali pada keadaan mentah, *torrefied* pada suhu 240 °C dan *torrefied* pada 270 °C. Pada keadaan tersebut, Kulim menunjukkan perbandingan LHV yang lebih tinggi daripada OPF dengan perbezaan 0.01 MJ/kg. Dengan membandingkan kedua-dua jenis biojisim (OPF dan Kulim), Kulim dipilih menjadi biojisim yang terbaik untuk pengelasan dan dalam keadaan *torrefied*.

## ABSTRACT

Abundances of oil palm waste from palm oil industry and forestry residue from logging activity leads to disposal problems. However these waste can be used as a renewable energy resources and can be upgraded to tackle biomass disadvantages through torrefaction process. Torrefaction is a process of heating at low temperature ranging from 200 – 300 °C under inert condition. Pre-treated biomass with torrefaction consequently upgrades the properties of biomass making it suitable for gasification. Different group of biomass have different properties thus it is essential to study the biomass characteristic. For biofuel, higher heating value (HHV) is important and the process to determine HHV is time consuming and prone to errors. This problem could be solved by introducing HHV correlations. Thus, the objectives of this study are to investigate the effect of torrefaction process at different temperatures and residence time for several types of biomass, to estimate correlations of higher heating value based on chemical properties of the biomass, and to apply biomass gasification using raw and torrefied biomass. The sources of biomass are from oil palm waste (oil palm frond, empty fruit bunch, palm mesocarp fibre and palm kernel shell) and forestry residue (meranti, seraya, kulim and chengal sawdust). Biomass torrefaction process was conducted in a tubular reactor at four different temperatures (240, 270, 300 and 330 °C), in an inert nitrogen atmosphere at three different residence time (15, 30 and 60 minutes). The torrefied biomass products were characterized in terms of heating value, mass and energy yield, proximate and ultimate analysis. The obtained data were then used to estimate the higher heating value correlations and served as the starting information for a fluidized bed gasification simulation run. Based on the result of mass and energy yields, the optimum residence time used for both biomass are at 30 minute. From the ultimate analysis, the carbon composition for both oil palm waste and forestry residue show an increasing trends while hydrogen and oxygen compositions for both types of biomass show decreasing trends. From proximate analysis, fixed carbon is increased up to 56 wt% for oil palm waste and 47 wt% for forestry residue. For hydrogen to carbon and oxygen to carbon ratios, it showed a decreasing trend. The higher heating value increased as the enhancement factor for HHV reached up to 1.58 and 1.41 for oil palm waste and forestry residue respectively. On model development for the prediction of higher heating value, linear correlation based on proximate analysis gives the best estimate for oil palm waste (average absolute error (AAE): 5.37%) and forestry residue (AAE: 10.37%). Through gasification simulation, it is noted that the best biomass to be used from oil palm waste is oil palm frond (OPF) while for forestry residue is Kulim sawdust. Further analysis shows that both biomass produced the highest hydrogen gas when it is operated at gasification temperature of 700 °C, air to biomass ratio (ABR) of 0.2 and steam to biomass ratio (SBR) of 1.0. Using this operating condition, cold gas efficiency (CGE) and lower heating value (LHV) of the syngas are calculated. CGE changes for OPF is in the range of 0.85% to 6.29%, while for Kulim sawdust, the increment is from 3.0% to 8.6%. Both biomass have almost similar LHV except for the biomass at raw condition, torrefied at 240 °C and torrefied at 270 °C. Kulim sawdust shows a higher LHV than OPF with the different of 0.01 MJ/kg. By comparing both types of biomass (OPF and Kulim sawdust), Kulim sawdust is chosen to be the best biomass to be gasified under torrefied condition.



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## LIST OF SYMBOLS

$\alpha$	Mechanism factor
$\beta$	Fraction of steam consume by reaction
$m_i$	Initial mass of biomass
$m_f$	Final mass of biomass
$m_t$	Weight of crucible and biomass
$m_c$	Weight of crucible
$N$	Total number of sample
$i$	Specific sample of a biomass
$y_e$	Mass fraction of experimental biomass
$y_p$	Mass fraction of predicted biomass
$t_{dif}$	Temperature different
$W$	constant value (2409.26 cal/°C)
$b_{fuse}$	Length of burn fuse wire
$m$	Mass of biomass
$LHV_{PG}$	Lower heating value of product gas
$LHV_{Bio}$	Lower heating value of biomass
$\dot{m}_{PG}$	Mass flow rates of product gas
$\dot{m}_{Bio}$	Mass flow rates of biomass
$\chi_{CO}$	Composition of carbon monoxide
$\chi_{H_2}$	Composition of hydrogen
$\chi_{CH_4}$	Composition of methane



## LIST OF ABBREVIATIONS

OPW	Oil palm waste
FR	Forestry residue
C	Carbon
H	Hydrogen
N	Nitrogen
O	Oxygen
S	Sulphur
FC	Fixed carbon
VM	Volatile matter
MC	Moisture content
HHV	Higher heating value
H/C	Hydrogen to carbon ratio
O/C	Oxygen to carbon ratio
ABR	Air to biomass ratio
SBR	Steam to biomass ratio
CGE	Cold gas efficiency
LHV	Lower heating value
RMSE	Root mean square error
AE	Absolute error
AAE	Average absolute error

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